# Combining Estimates and Economics

# Workshop Summary

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# Why Simulation?

# Metal Content Is Known From Grade and Tonnage Data

| Deposit | Tons | Cu grade% | Tons Cu |
|---|---|---|---|
| A | 6,400,000 | 1.7 | 108,800 |
| B | 221,000 | 1.2 | 2,652 |
| C | 93,000 | 4.37 | 4,064 |
| D | 1,260,000 | 1.6 | 20,160 |
| E | 447,000 | 0.71 | 3,174 |
| | | **MEAN =** | **27,770** |

# Expected Amounts of Undiscovered Metals Can Be Estimated

- Expected number of undiscovered deposits is easy to estimate
  (= $0.233N_{90}+0.4N_{50} + 0.225N_{10} +0.045N_{05} + 0.03N_{01}$
  Where, $N_z$ is estimated number of deposits associated with $z^{th}$ quantile)

- For example, if the 90th, 50th, 10th, 5th, and 1st estimates were: 1, 3, 6, 9, 12 deposits, the expected number of deposits = 6

- From previous slide, the expected amount of metal/deposit = 27,770 tons, the total expected amount of undiscovered metal = 6 x 27,770 = 166,620 tons

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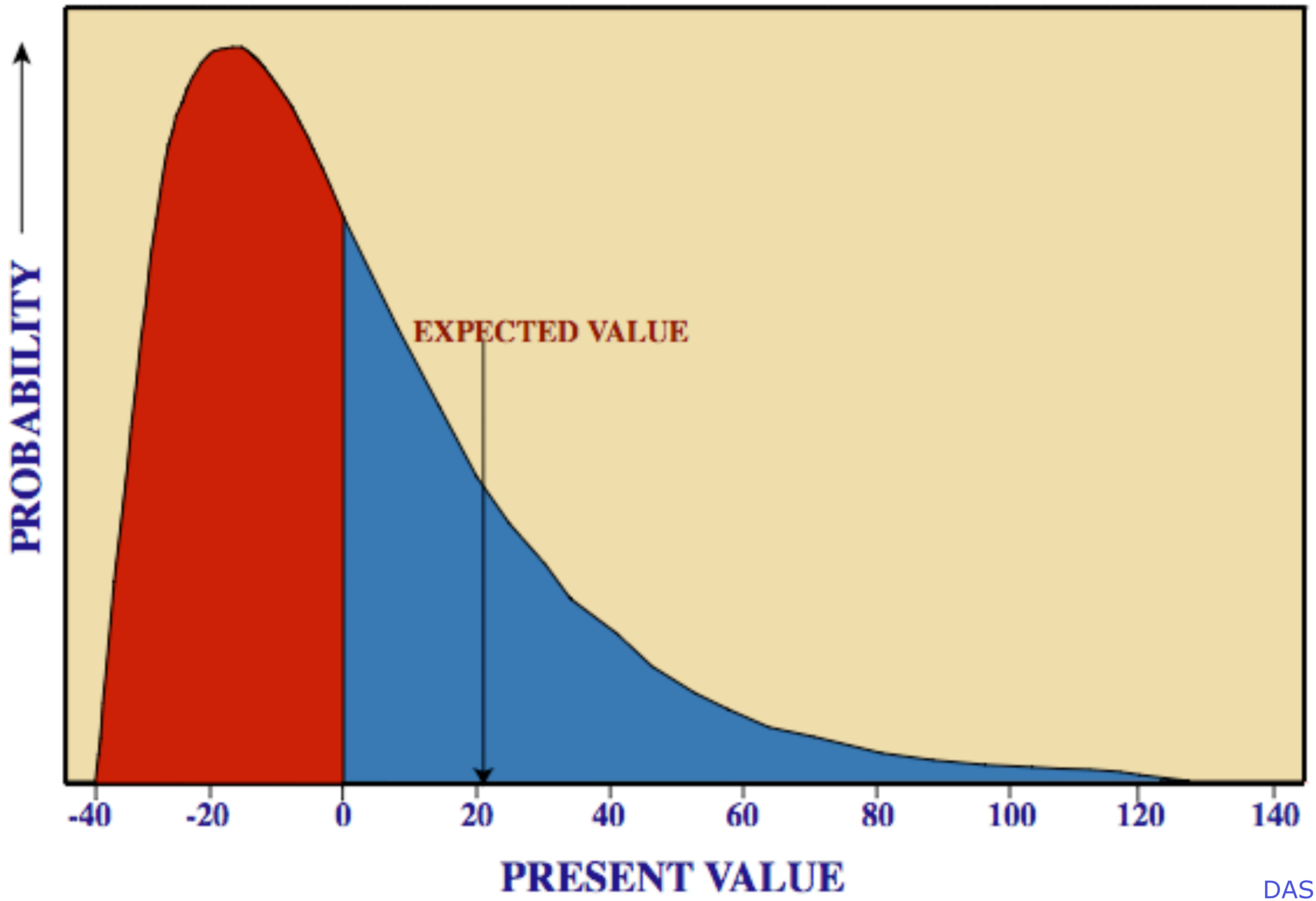
# A Decision-maker Needs to Be Keenly Aware Of:

- The expected outcome
- The probabilities of other outcomes

# Probability of Economic Success

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# A Goal of Three-part Assessments:

**Provide decision-makers with unbiased information about the expected values and probabilities of other values/outcomes of undiscovered mineral resources**

Expected values and probabilities of amounts of metals or economic value can be estimated via equations if certain assumptions are made (Allais, 1956)

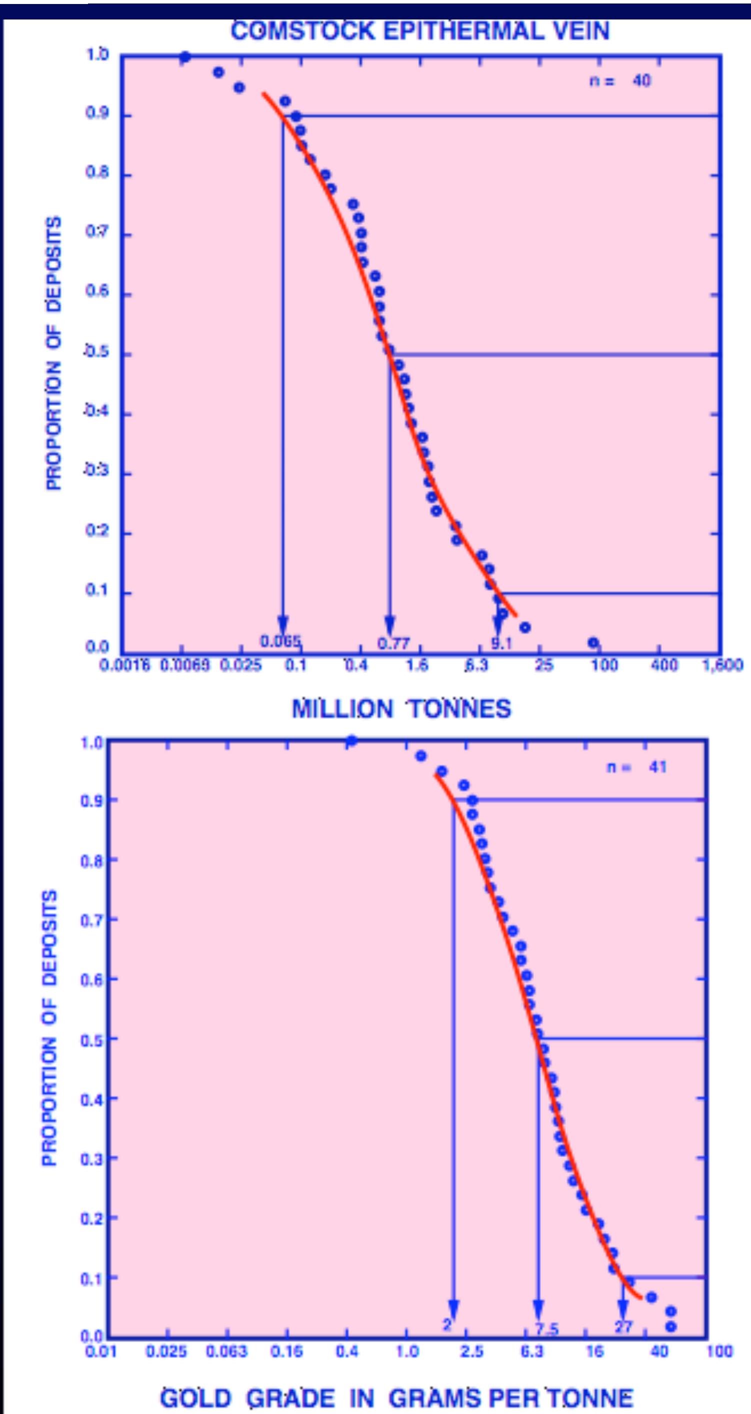
The assumptions (Poisson distribution of number of deposits and lognormal distribution of tonnage and most grades) were used by Drew in 1986 in the first simulator to estimate amounts of metal. (MARK1?)

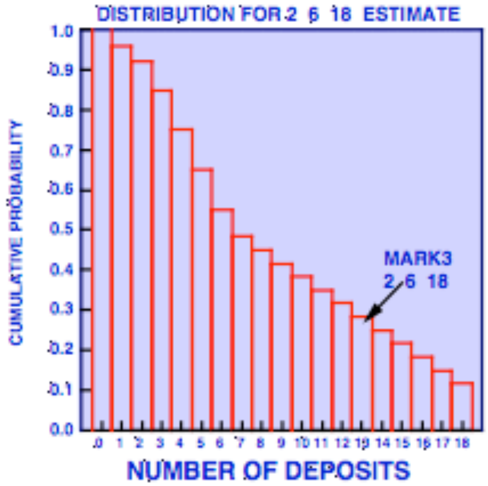
# MARK3/EMINERS

**The algorithms developed by Dave Root (Root et al., 1992) freed us from the assumptions of the Poisson and the lognormal distributions and provided distribution-free methods of calculating probabilities of number of deposits, tonnages, and quantities of contained metal in a Monte Carlo simulation. (MARK3)**

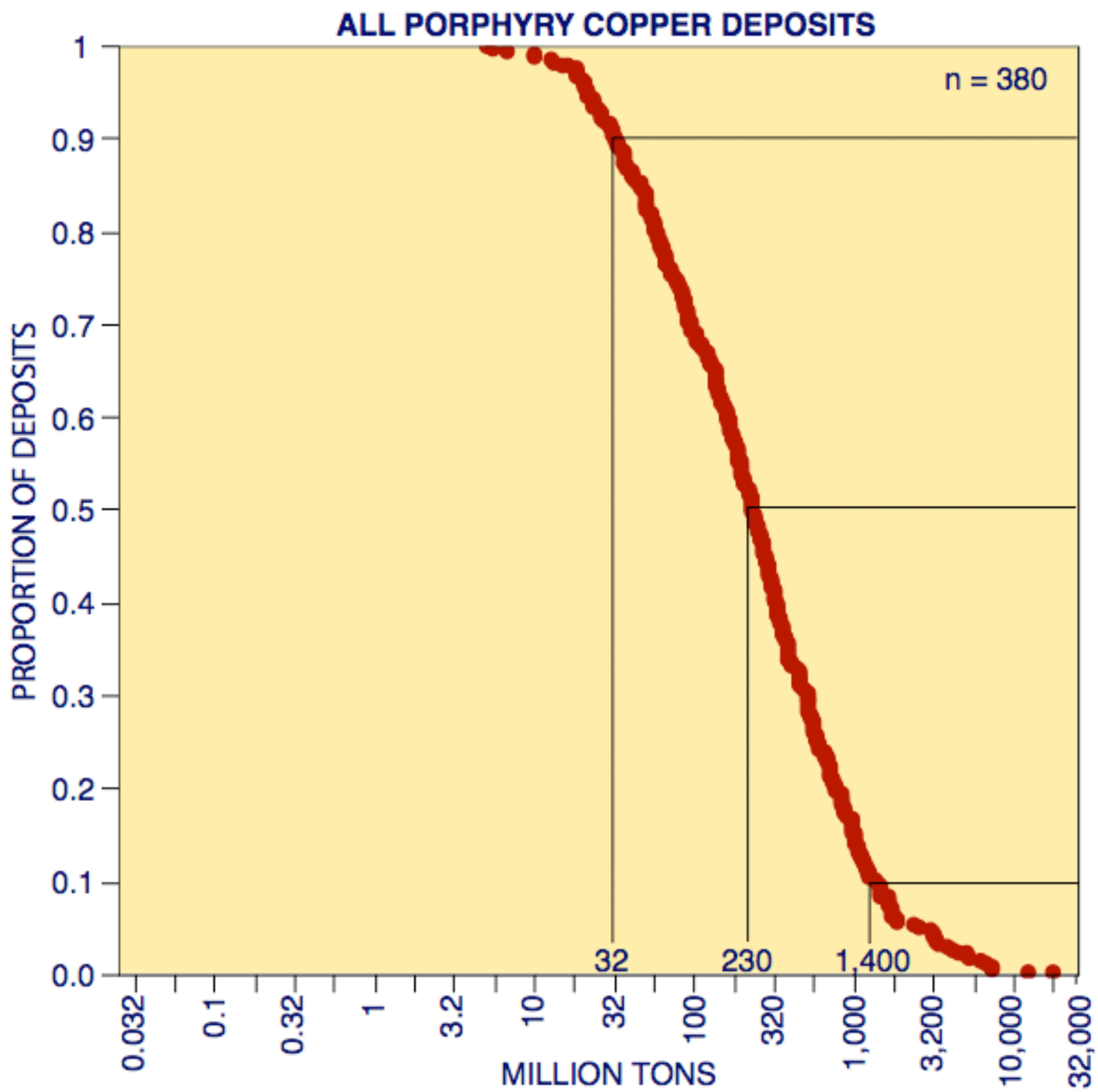
# Combining Grade and Tonnage Models and Undiscovered Deposits Estimates

(Root, Menzie, and Scott, 1992)



# Porphyry Copper G-T Model

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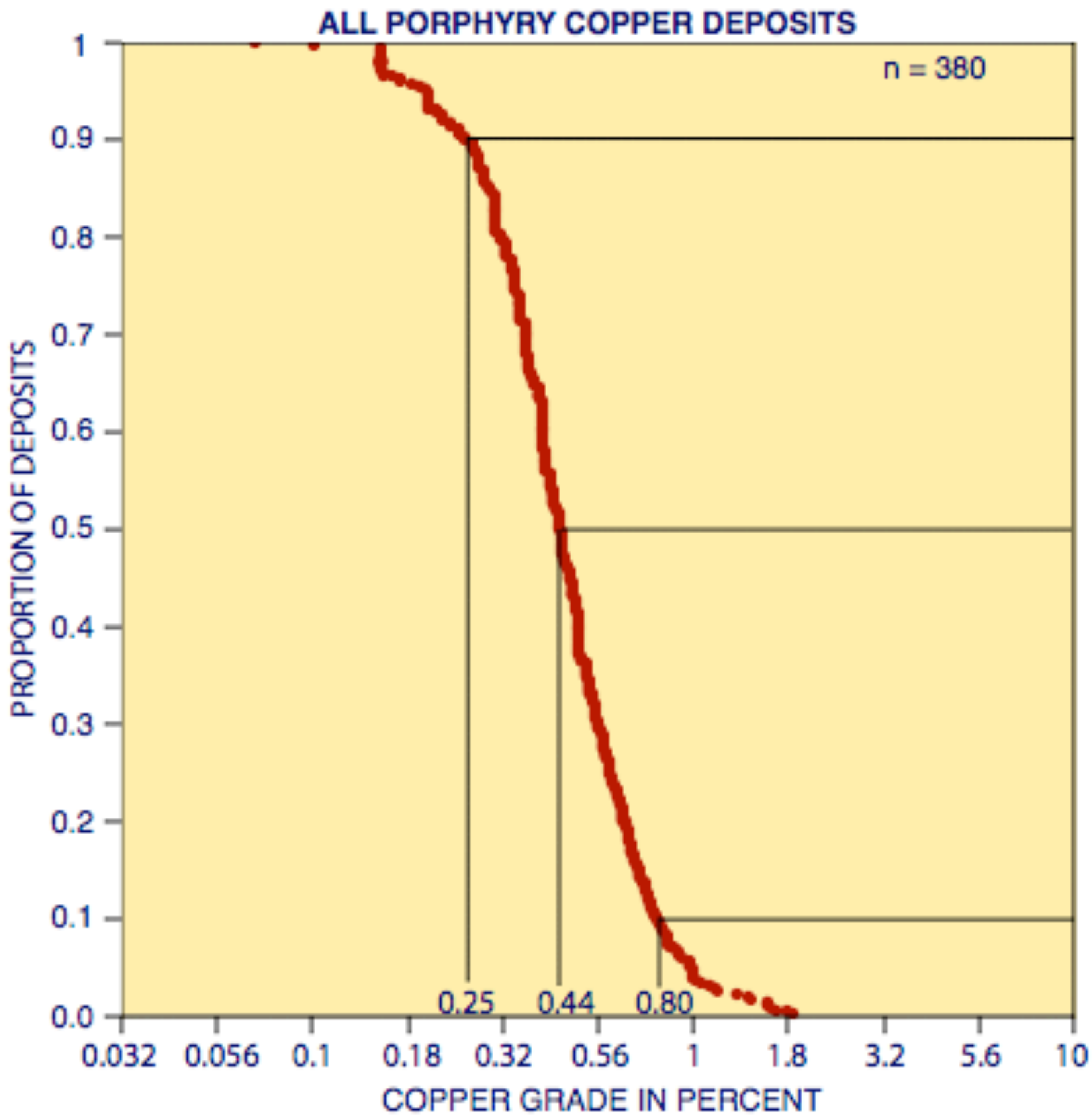
ALL PORPHYRY COPPER DEPOSITS
n = 380
PROPORTION OF DEPOSITS
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.25
0.44
0.80
0.032
0.056
0.1
0.18
0.32
0.56
1
1.8
3.2
5.6
10
COPPER GRADE IN PERCENT

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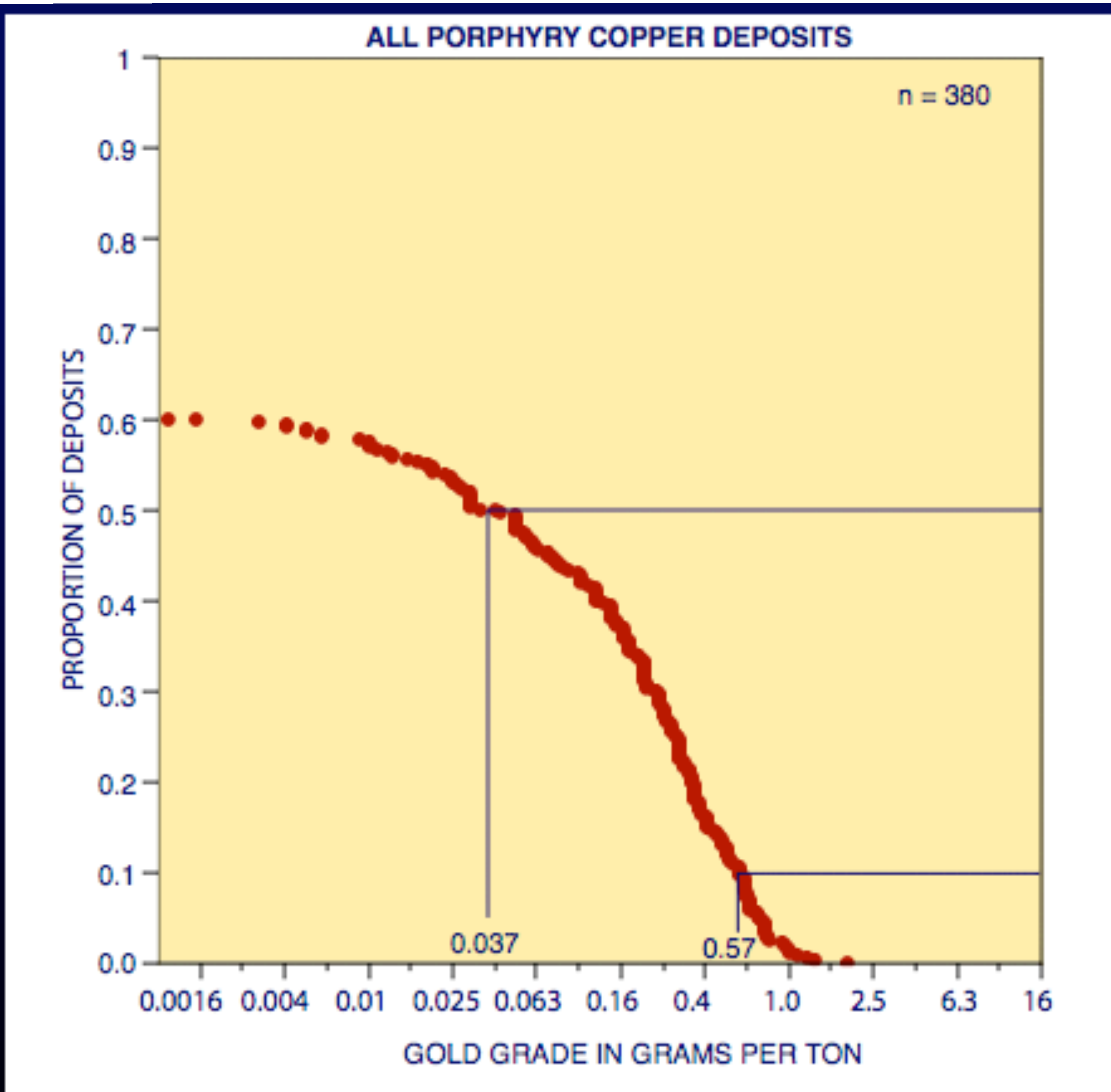
ALL PORPHYRY COPPER DEPOSITS
n = 380
PROPORTION OF DEPOSITS
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.037
0.57
0.0016 0.004 0.01 0.025 0.063 0.16 0.4 1.0 2.5 6.3 16
GOLD GRADE IN GRAMS PER TON

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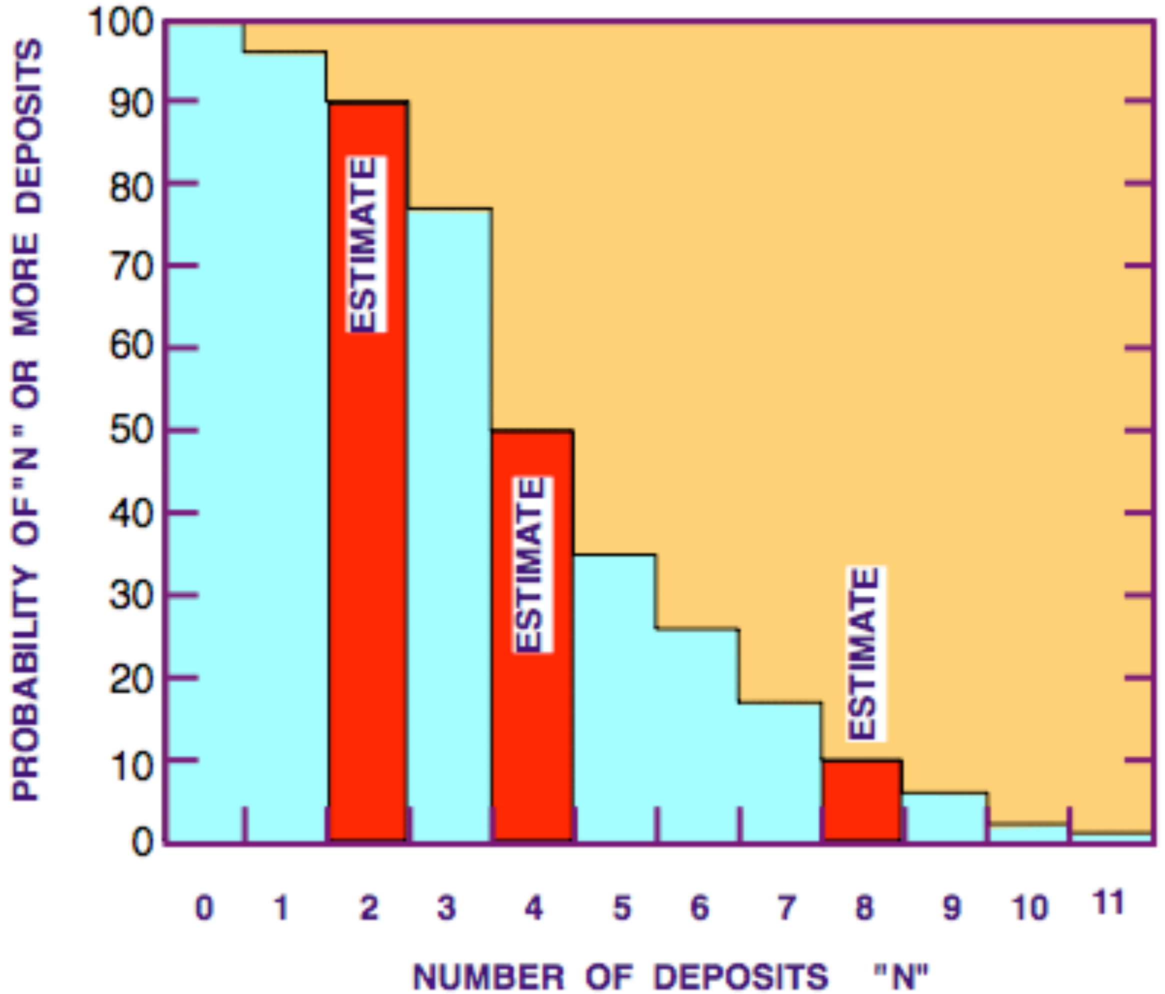
# How Does It Work?

# Estimating Undiscovered Deposits—
## the form of the estimates

**The relation of quantile estimates for probabilities of 0.9, 0.5, and 0.1 to the underlying probability distribution**

**(quantile = variate-value divides total freq. into n equal intervals)**




Three estimates of number of undiscovered deposits with interpolated values.

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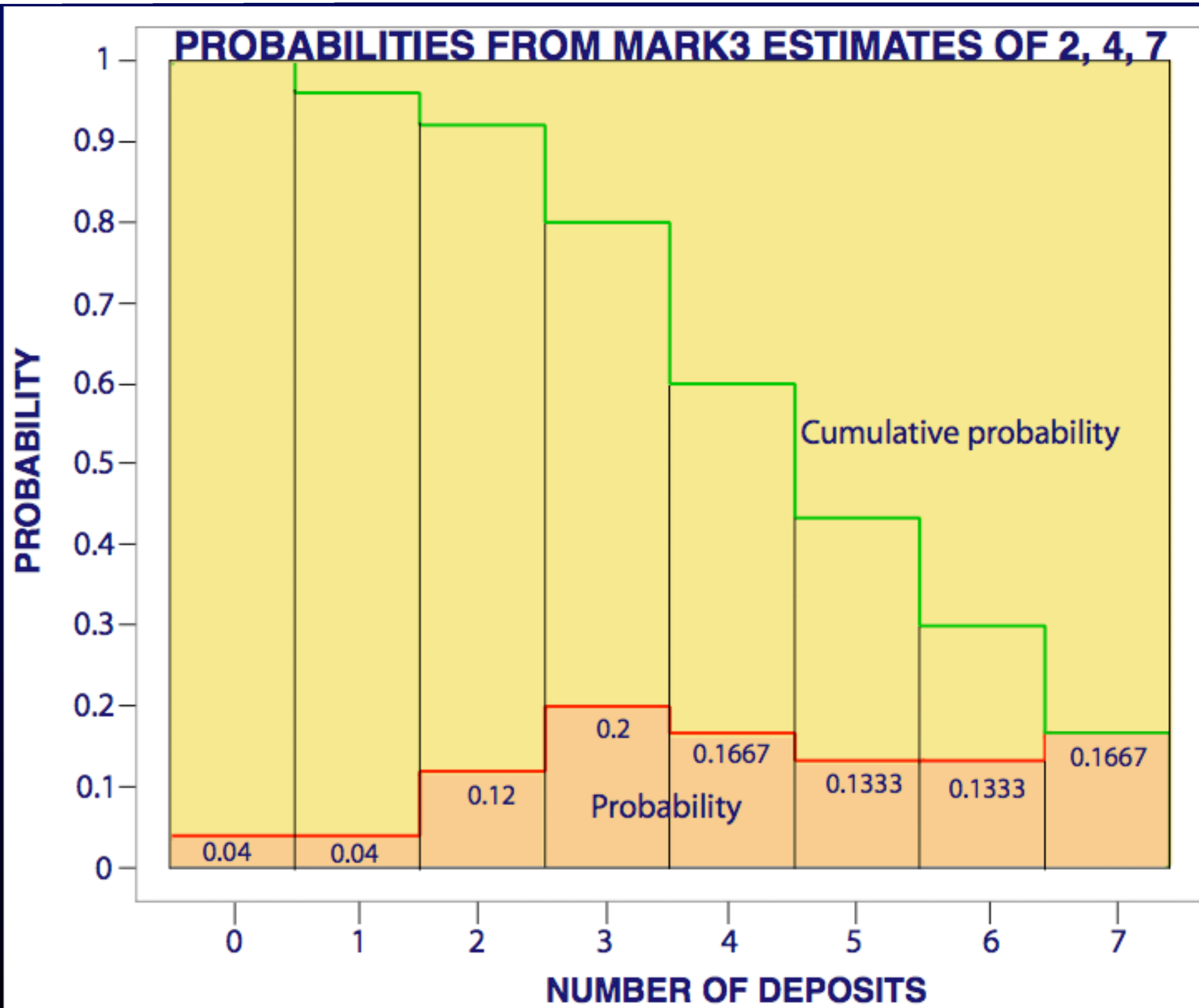
PROBABILITIES FROM MARK3 ESTIMATES OF 2, 4, 7
PROBABILITY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Cumulative probability
Probability
0.04
0.04
0.12
0.2
0.1667
0.1333
0.1333
0.1667
0
1
2
3
4
5
6
7
NUMBER OF DEPOSITS

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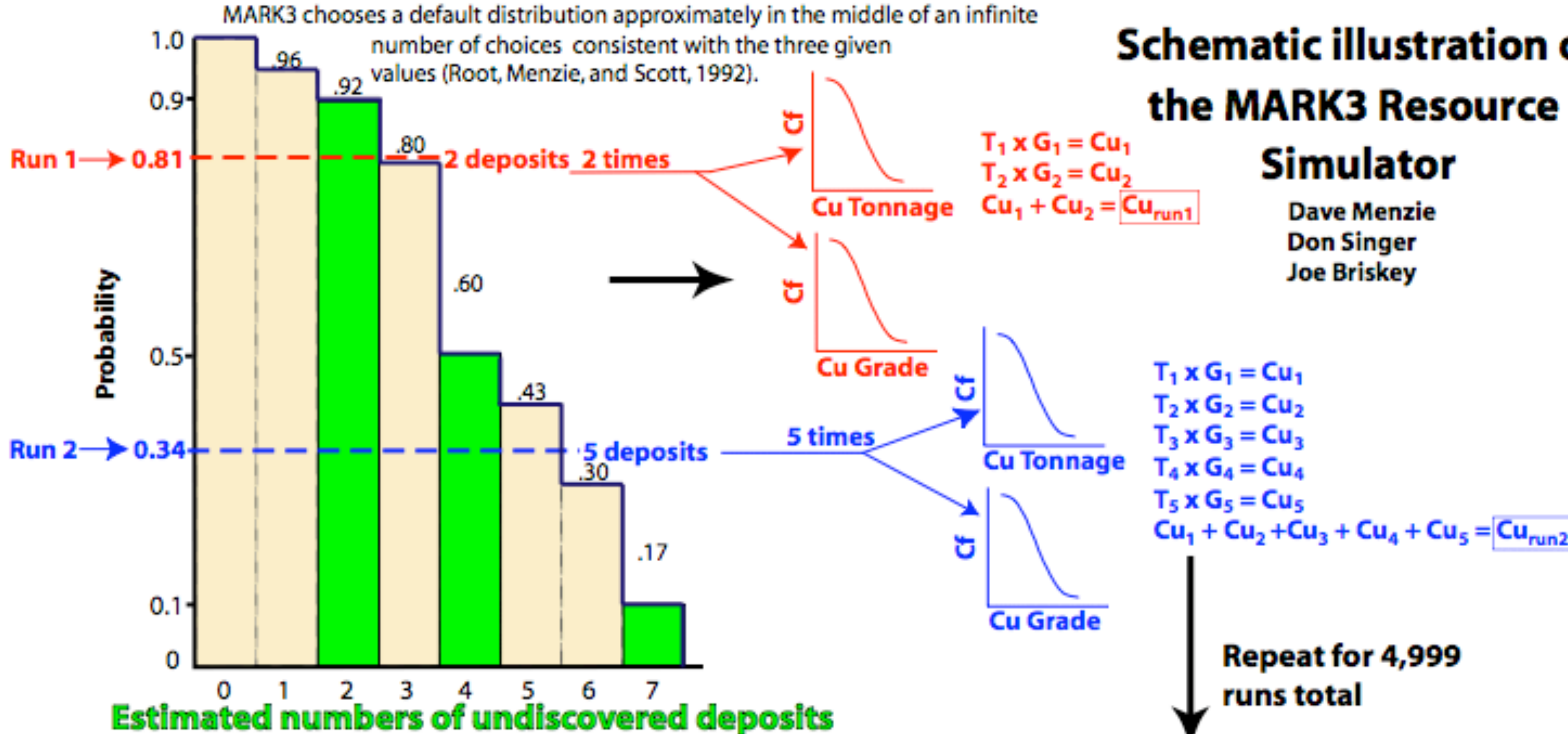
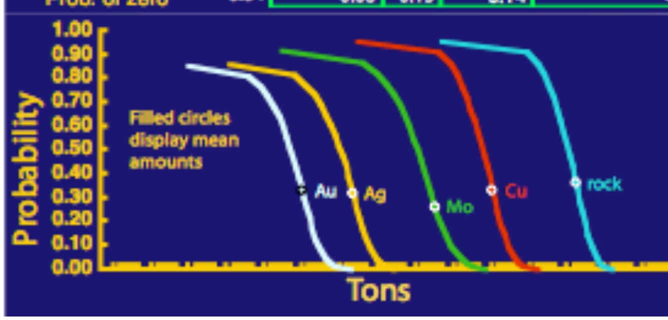
# Schematic illustration of the MARK3 Resource Simulator

Dave Menzie
Don Singer
Joe Briskey




Estimated amounts of contained metal and mineralized rock (metric tons)

| Quantile | Cu | Mo | Au | Ag | Rock |
|---|---|---|---|---|---|
| 0.95 | 160,000 | 0 | 0 | 0 | 35,000,000 |
| 0.90 | 990,000 | 1,800 | 0 | 0 | 210,000,000 |
| 0.50 | 12,000,000 | 220,000 | 100 | 2,000 | 2,100,000,000 |
| 0.10 | 52,000,000 | 1,600,000 | 526 | 11,000 | 8,500,000,000 |
| 0.05 | 76,000,000 | 2,900,000 | 750 | 16,000 | 12,000,000,000 |
| mean | 22,000,000 | 640,000 | 210 | 4,300 | 3,400,000,000 |
| Prob. ≥ mean | 0.33 | 0.26 | 0.33 | 0.32 | 0.36 |
| Prob. of zero | 0.04 | 0.08 | 0.15 | 0.14 | 0.04 |




| Run | Cu | Cu Sort | P(X≥x)= 1-(run number-1)/total number of runs) |
|---|---|---|---|
| 1 | 10 | 0 | 1 |
| 2 | 15 | 5 | 0.9 |
| 3 | 25 | 10 | 0.8 |
| 4 | 17 | 15 | 0.7 |
| 5 | 100 | 17 | 0.6 |
| 6 | 80 | 25 | 0.5 |
| 7 | 5 | 55 | 0.4 |
| 8 | 0 | 70 | 0.3 |
| 9 | 70 | 80 | 0.2 |
| 10 | 55 | 100 | 0.1 |
| . | | | |
| . | | | |
| 4,999 | | | |

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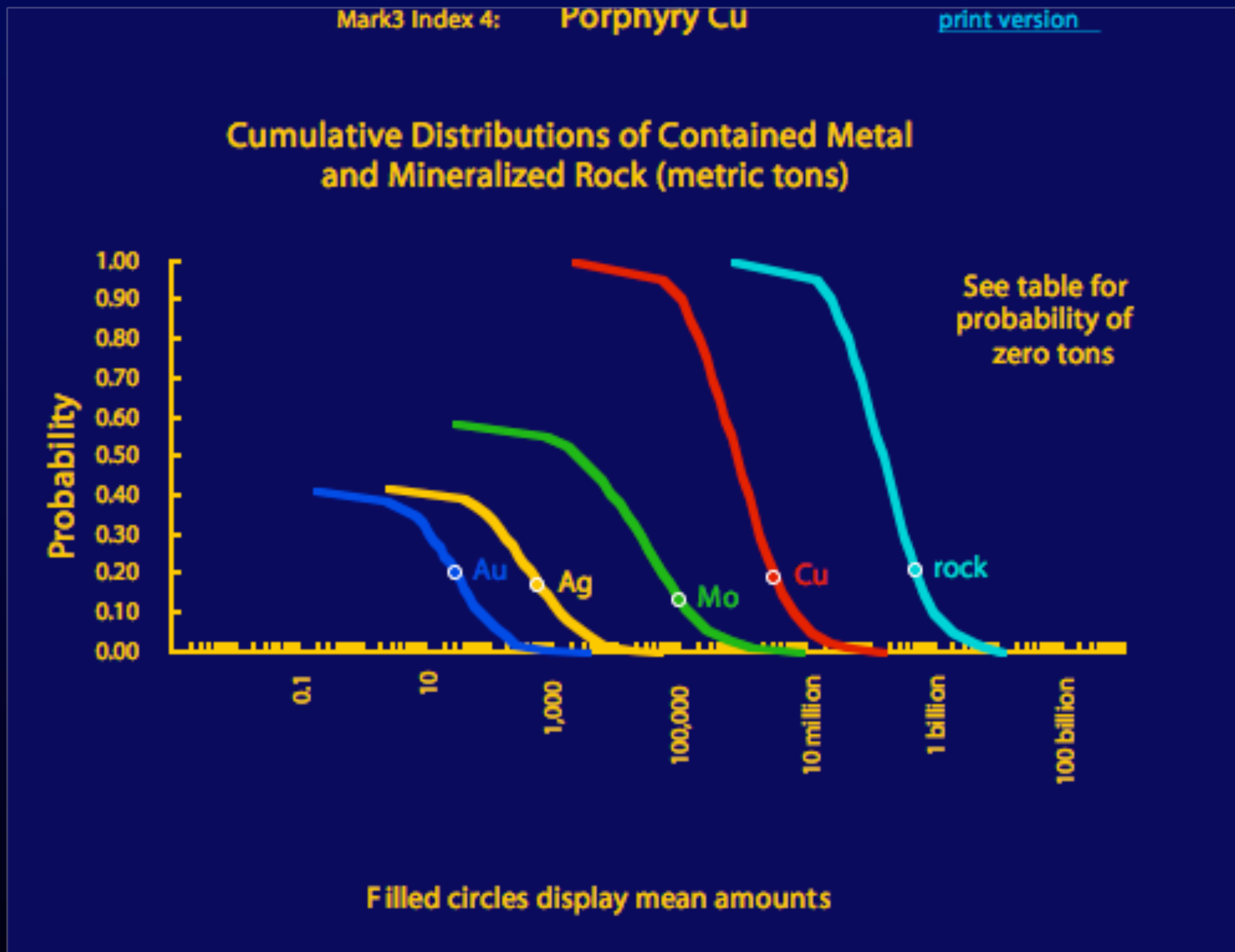
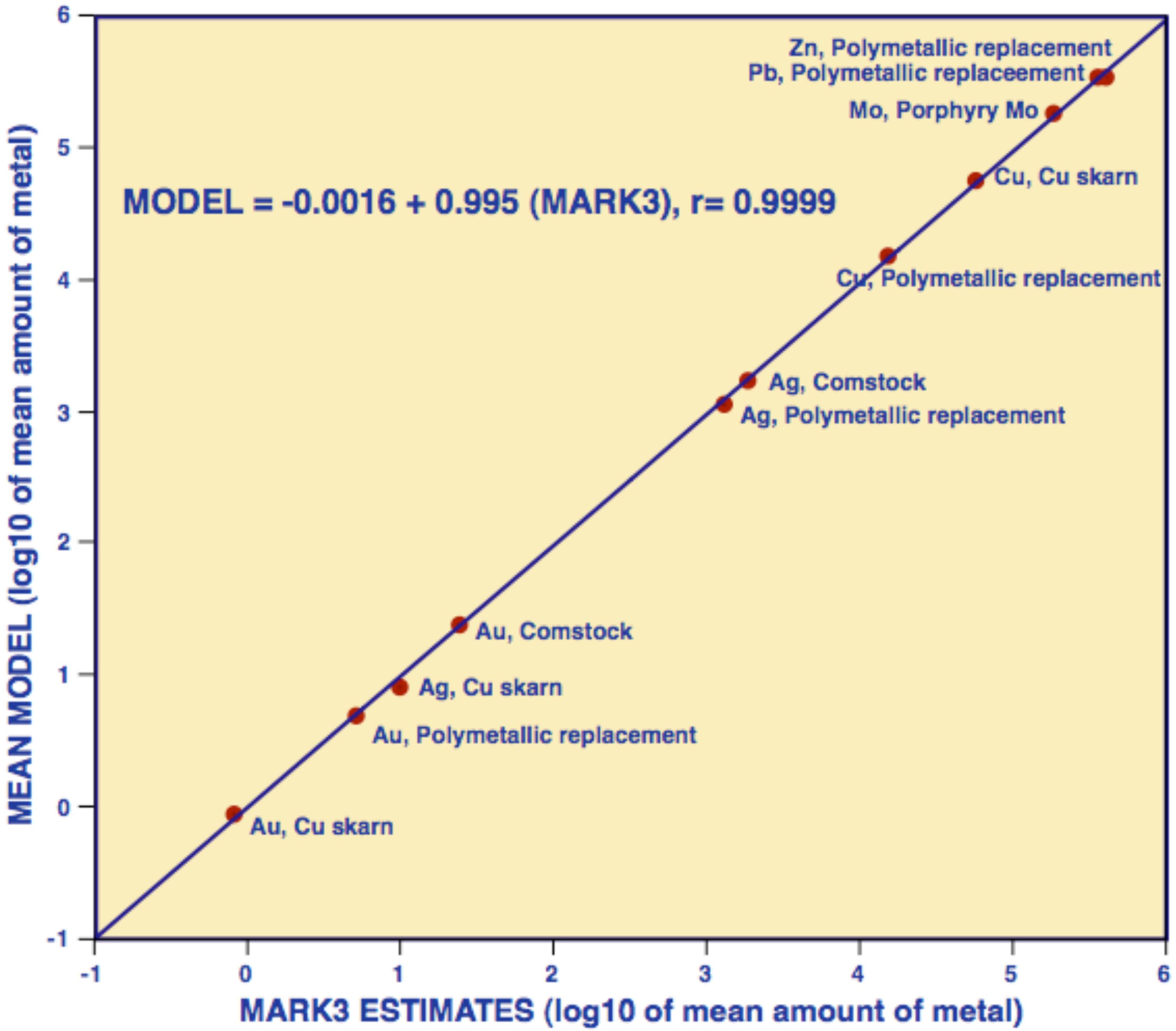
# Combined Grades, Tonnages, and Number of Deposits from MARK3 Simulator




Source of plot: USGS (1996) Open File Report 96-96 http://pubs.usgs.gov/openfile/of96-096/




Test of possible bias in MARK3 simulations (2003 version).

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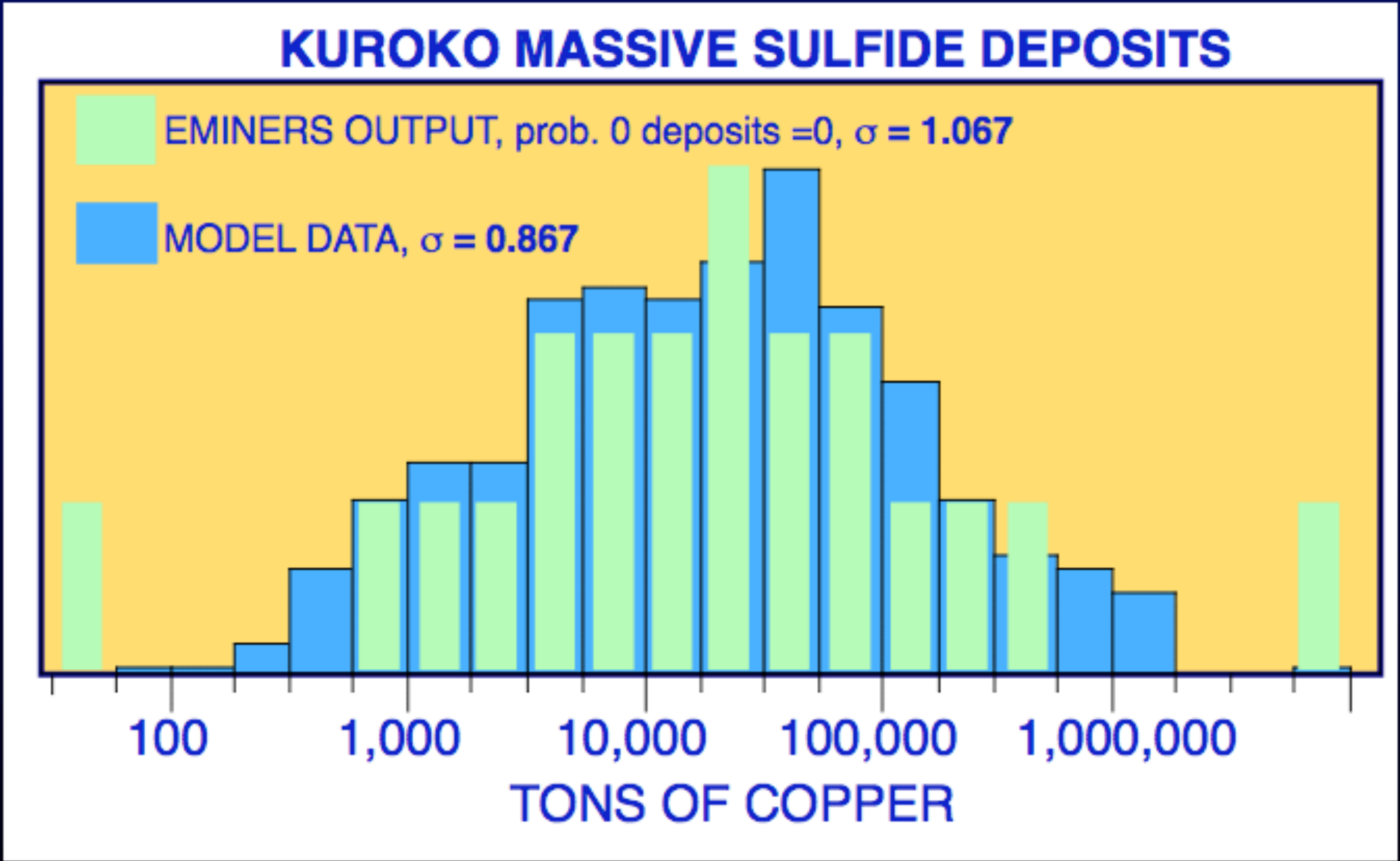
# EMINERS vs. MODEL



# Including Economic Filters: EMINERS

**EMINERS, developed by Joe Duval (2001) allowed:**

**Adding new models by user**

**Use of some economic filters**

# Cost Models

Developed by USBM (Camm, 1991; Smith, 1992) based on detailed costing of 3-6 mines per mining/milling method.

Tested and refined with general costs and mining rates from 10-40 mines per mining/milling method (Singer, Menzie, and Long, 1998, 2000; Long and Singer, 2001).

# Cost Models

Although not all costs are included and the estimates are rough, these models serve to discriminate clearly uneconomic from clearly economic deposits at an early assessment stage

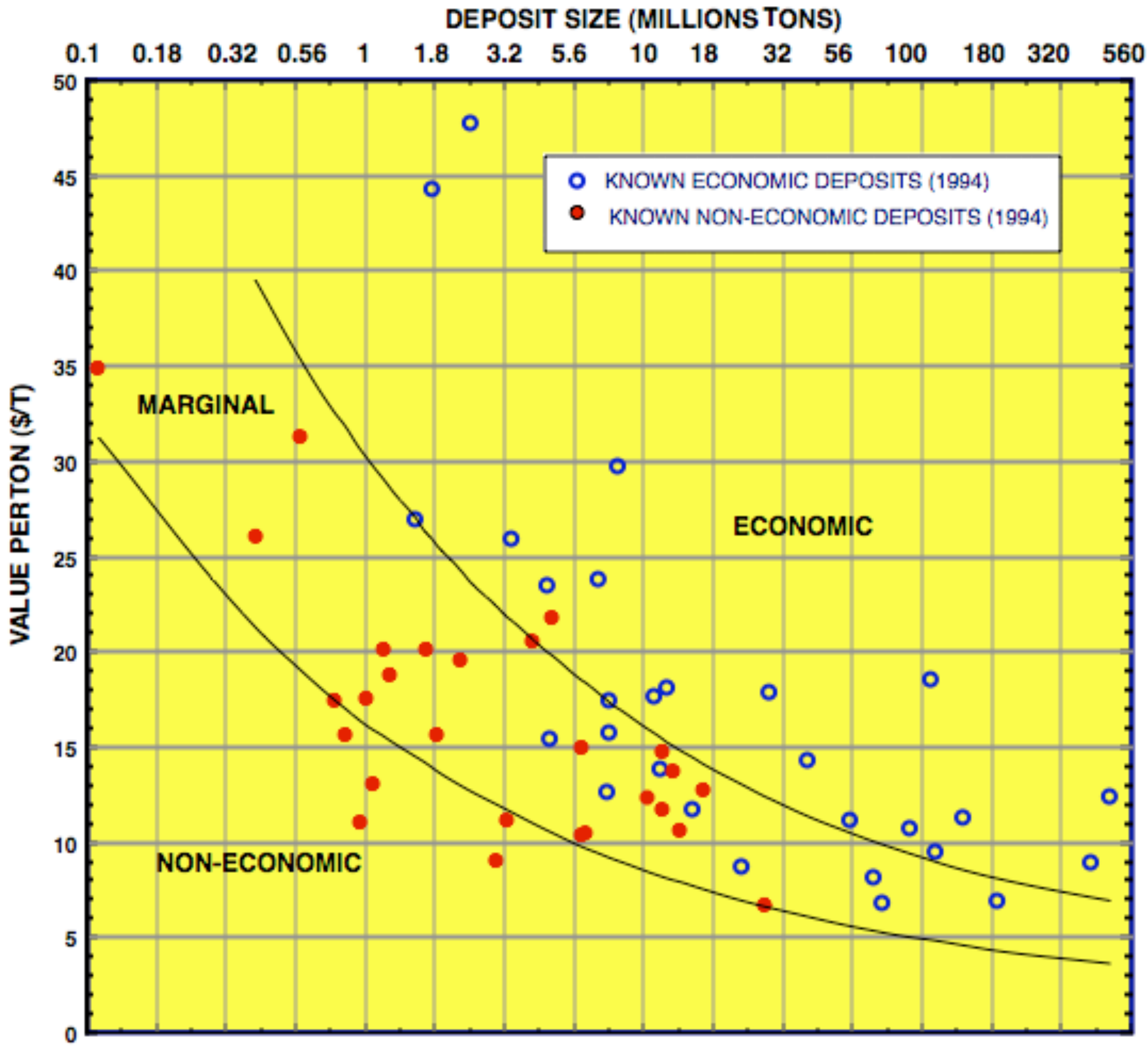



Figure 4--Relationship between value per short ton and deposit size (tons of ore) for U. S. open pit, heap-leach gold-silver deposits. Economic filters of 0.7 and 1.3 of break-even values based on a gold price of $380/oz., silver price of $5/oz., and a 15 pecent rate of return.

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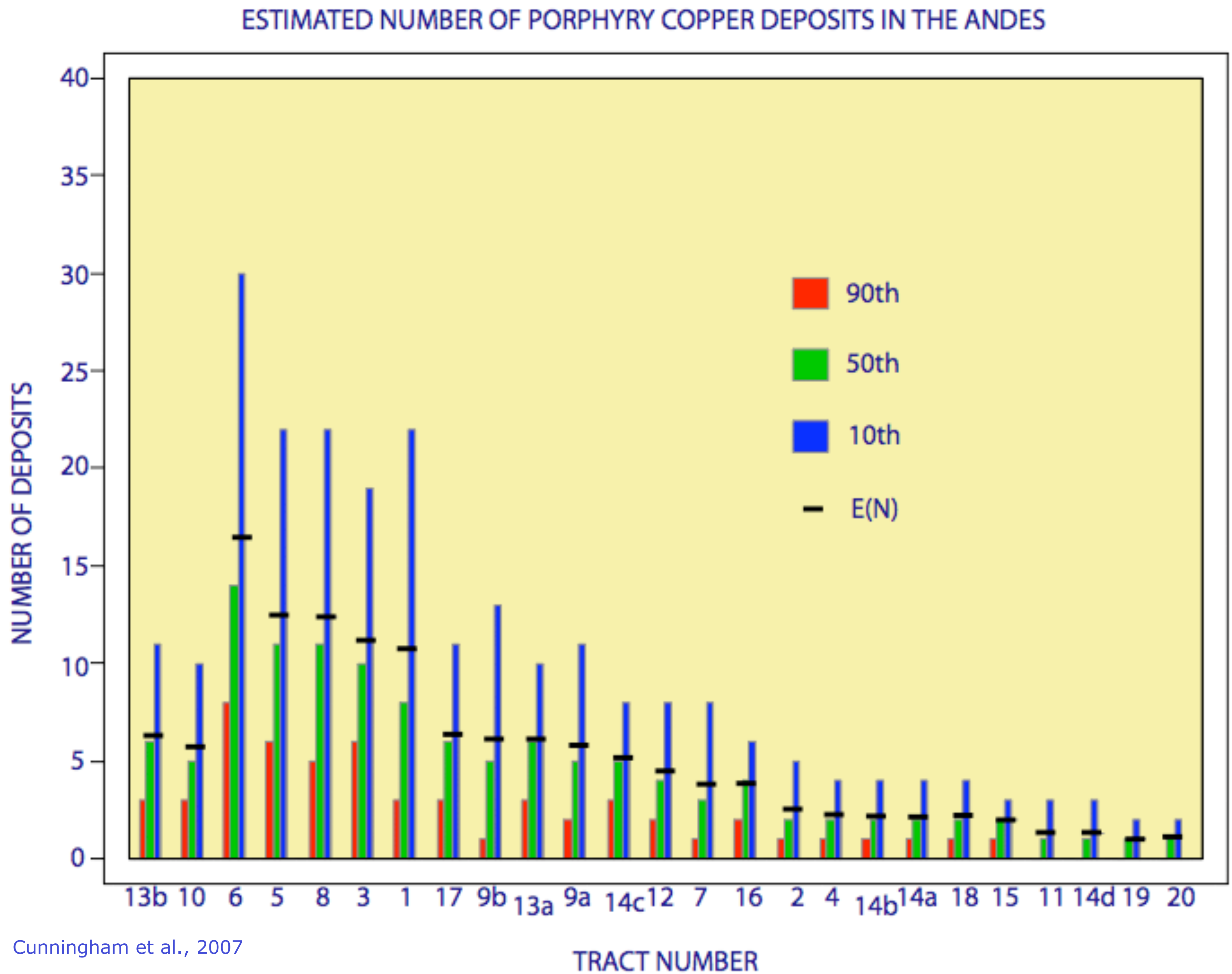
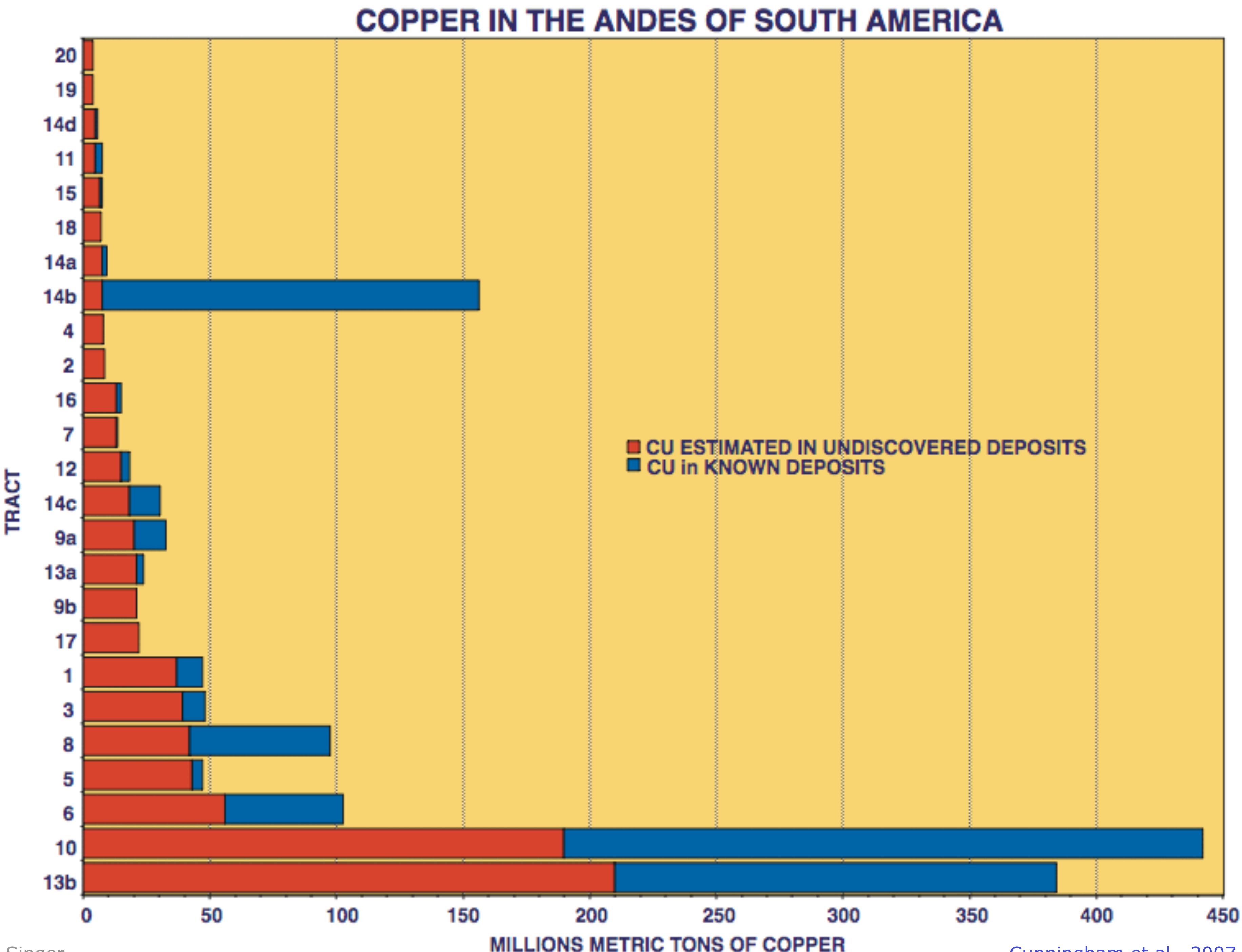
# Preliminary Testing Camm's Costing Models

- Preliminary analysis of 28 economic massive sulfide deposits, 46 economic open-pit U.S. Au-Ag mining operations , and 18 heap-leach (SX/EW) porphyry copper operations, suggest Camm's equations can be used as a basis for estimating costs
- Tests are in progress using recent economic examples to insure currency of estimates and to expand mining methods

# Some Examples of What Can Be Done With Output From MARK3/EMINERS




Cunningham et al., 2007

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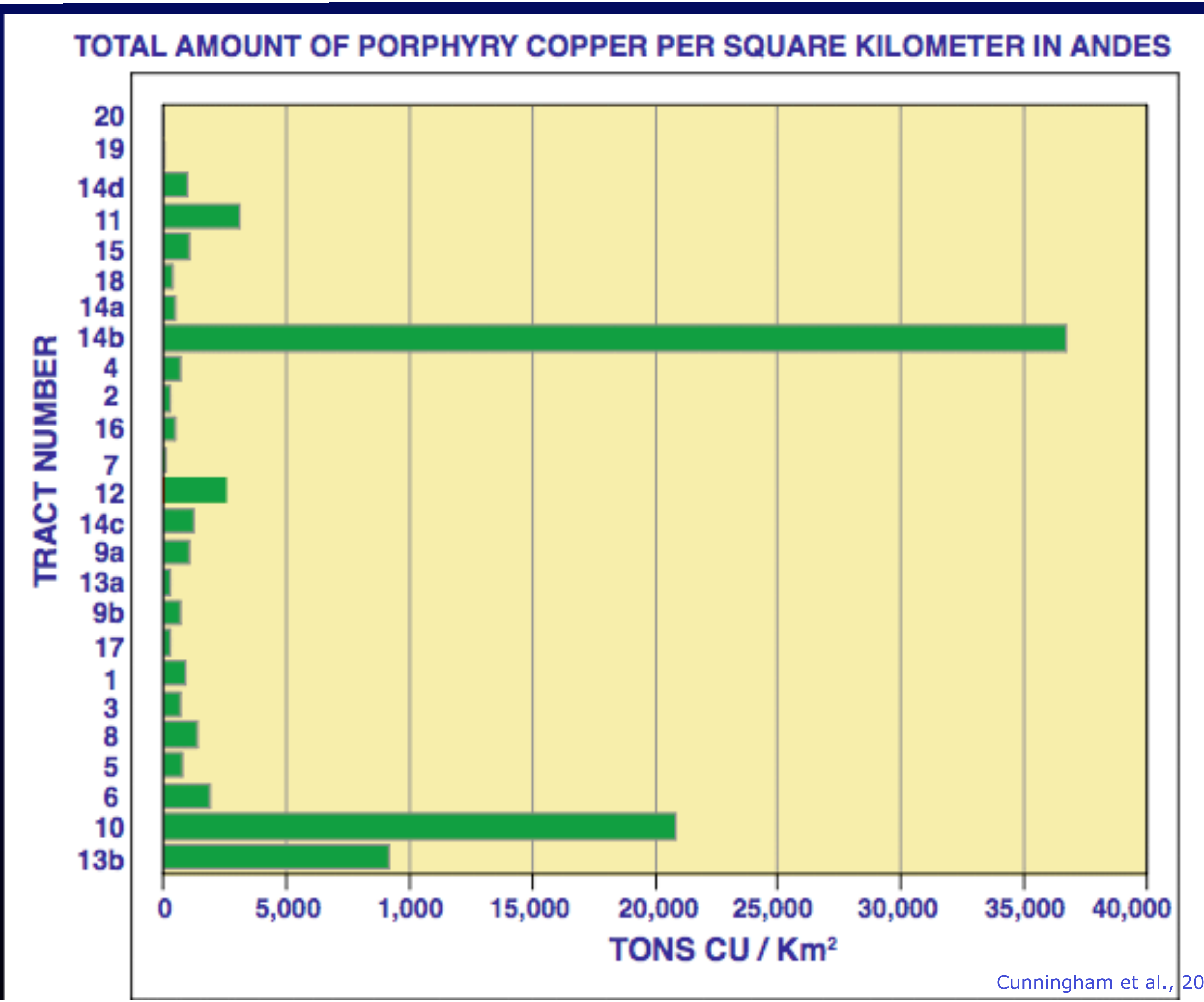
Cunningham et al., 2007

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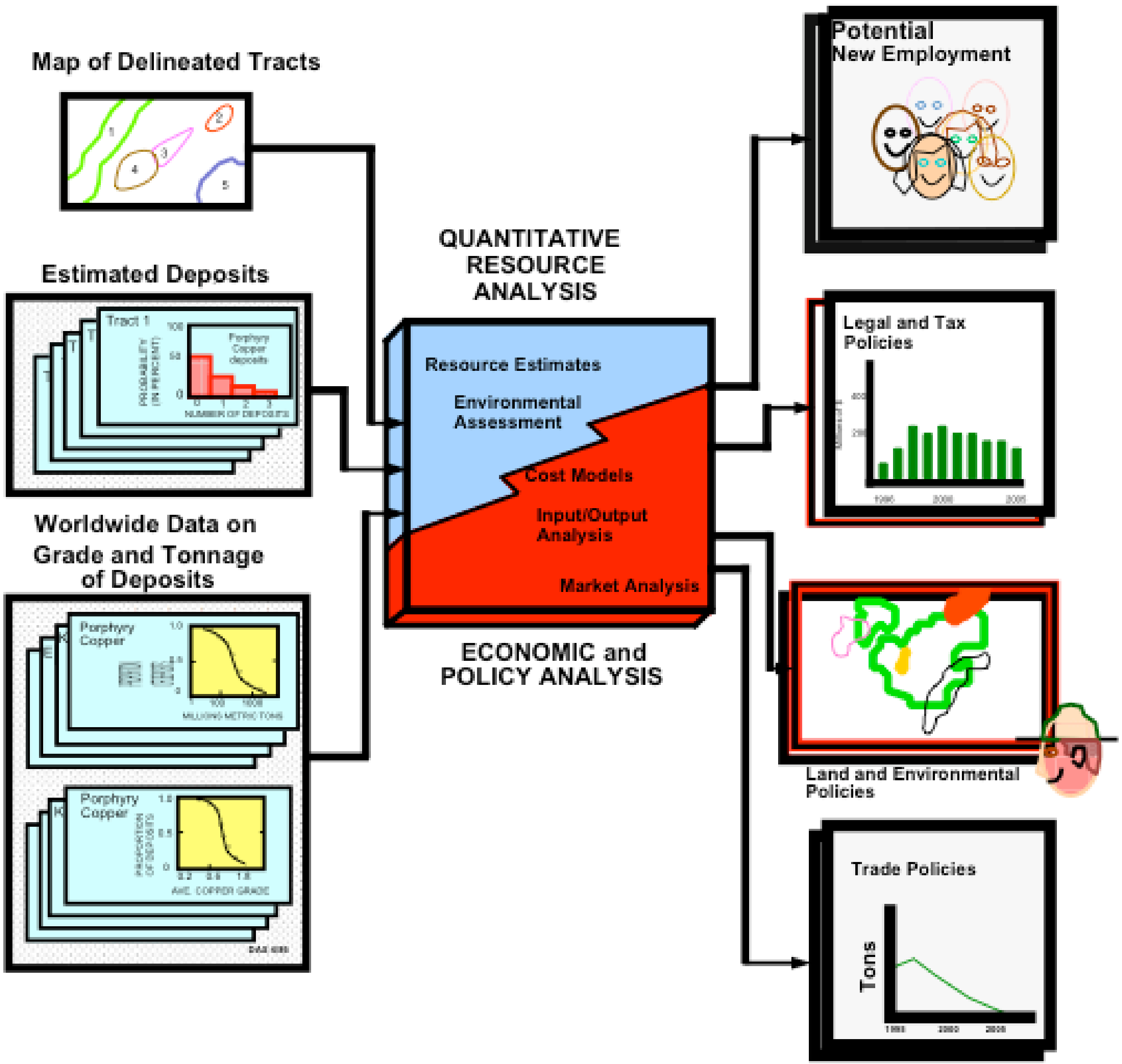
Cunningham et al., 2007



Map of Delineated Tracts
Estimated Deposits
Tract 1
Porphyry Copper deposits
PROBABILITY (IN PERCENT)
NUMBER OF DEPOSITS
Worldwide Data on Grade and Tonnage of Deposits
Porphyry Copper
MILLIONS METRIC TONS
Porphyry Copper
PROPORTION OF DEPOSITS
AVE. COPPER GRADE
QUANTITATIVE RESOURCE ANALYSIS
Resource Estimates
Environmental Assessment
Cost Models
Input/Output Analysis
Market Analysis
ECONOMIC and POLICY ANALYSIS
Potential New Employment
Legal and Tax Policies
Land and Environmental Policies
Trade Policies
Tons


Menzie, 2005

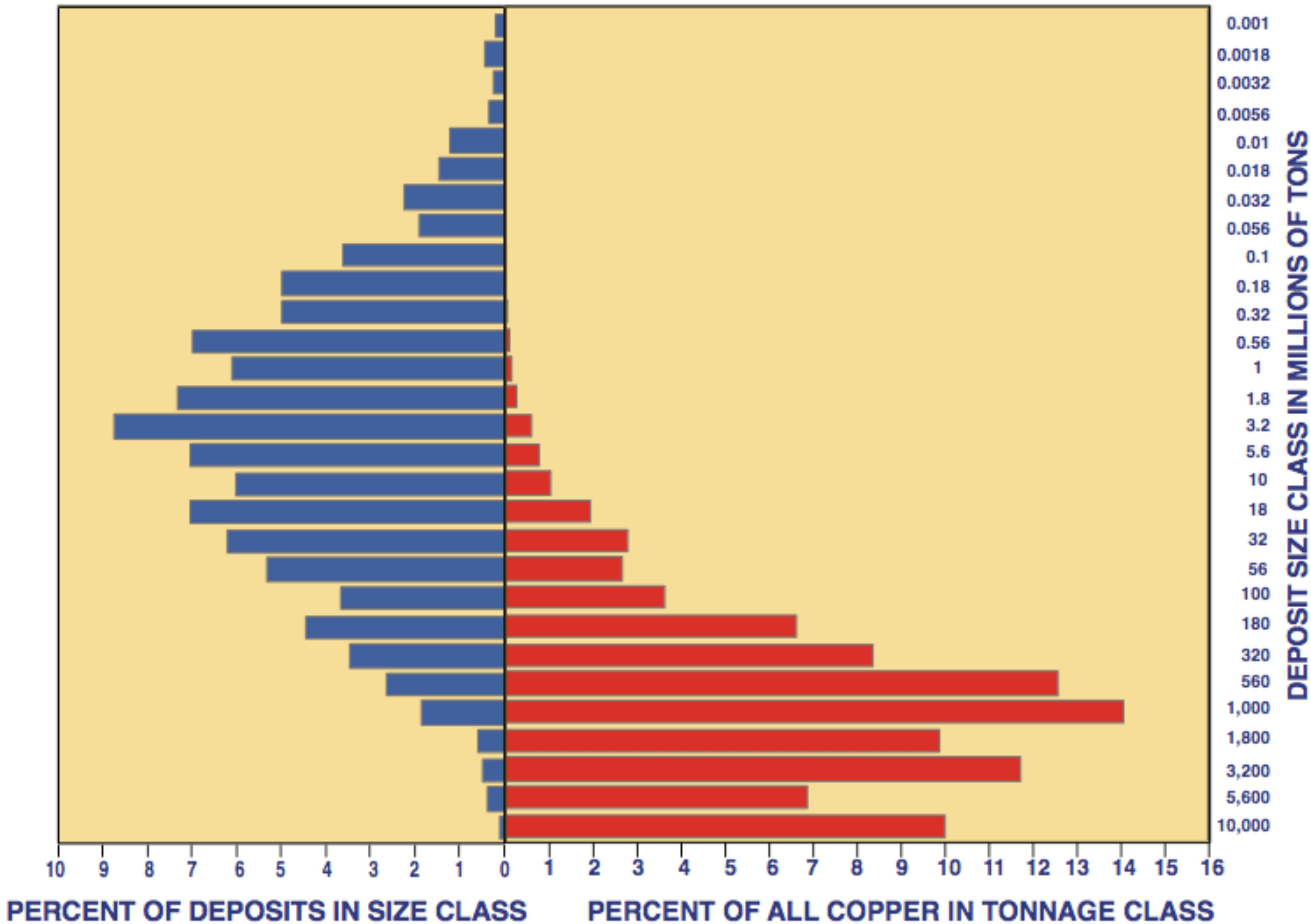
# MARK3/EMINERS Summary

- For most models tested MARK3/EMINERS are able to capture the expected amounts and probabilities of different amounts of metal due to effects of estimated number of deposits, tonnages, and grades
- For simplified cost models, work needs to be done to see that the proper mining methods are applied and the current costing algorithms are used

# Summary of Quantitative Mineral Resource Assessments

# What Was Covered

- Quantitative resource assessment (3-part)
  - The nature of mineral resources
  - A short history
  - Mineral deposit models
  - Descriptive
  - Grade and tonnage
  - Deposit density
  - Costs
- Delineation and Estimating number of undiscovered deposits
- Combining grades, tonnages, number of deposits, and costs and Summary




Proportion of copper metal and proportion of deposits by size of deposit for 2045 copper-bearing mineral deposits containing 2,065,000,000 metric tons of copper.

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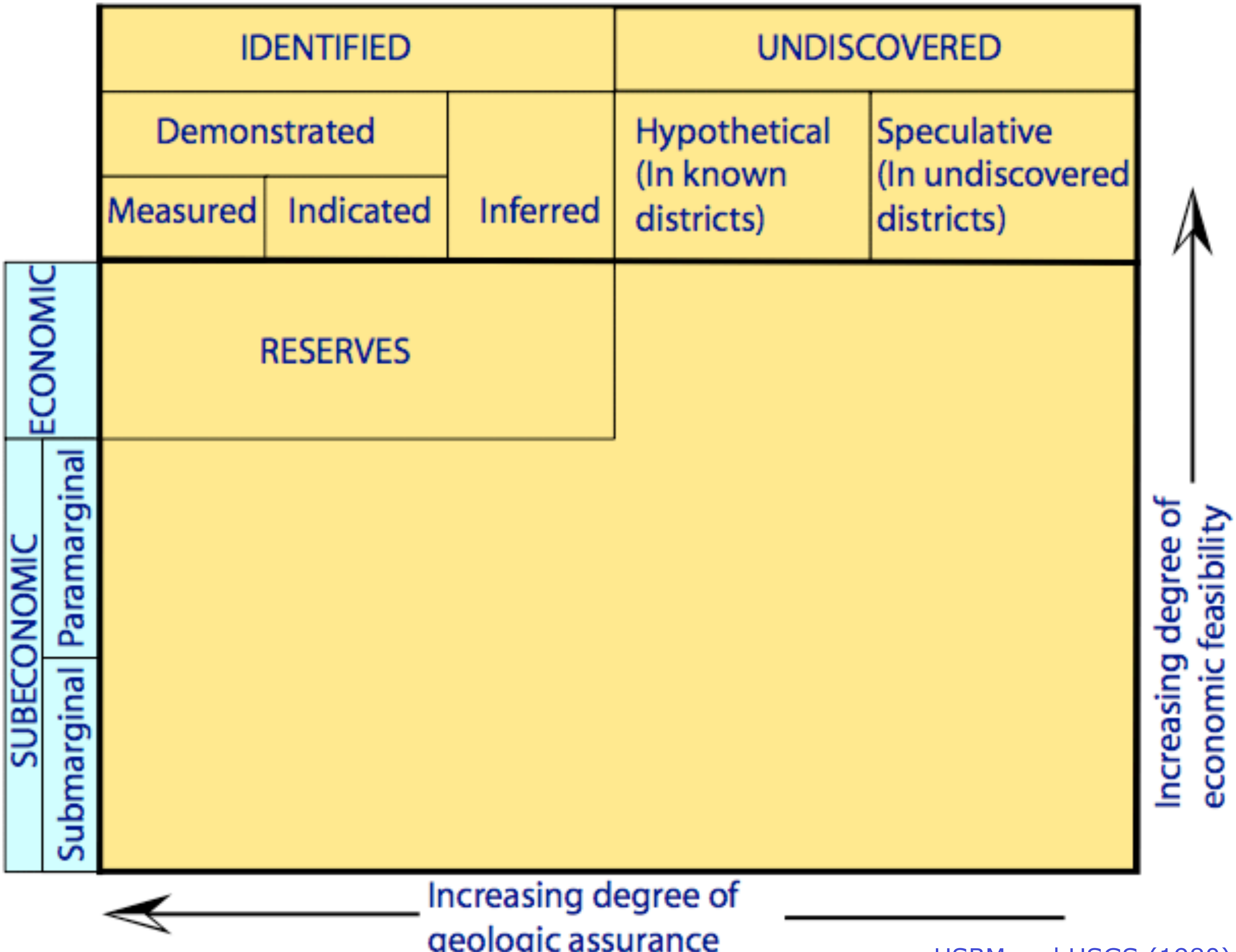
# United States Department of the Interior Classification System




USBM and USGS (1980)

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# Why Not Just Rank Prospects / Areas?

- Need for financial analysis
- Need for comparison with other land uses
- Need for comparison with distant tracts of land
- Need for consideration of economic and environmental consequences of possible development

# Three-part Resource Assessments

- **General locations of undiscovered deposits are delineated from a deposit type's geologic setting**
- **Frequency distributions of tonnages and grades of well-explored deposits serve as models of grades and tonnages of undiscovered deposits**
- **Number of undiscovered deposits are estimated probabilistically by type**

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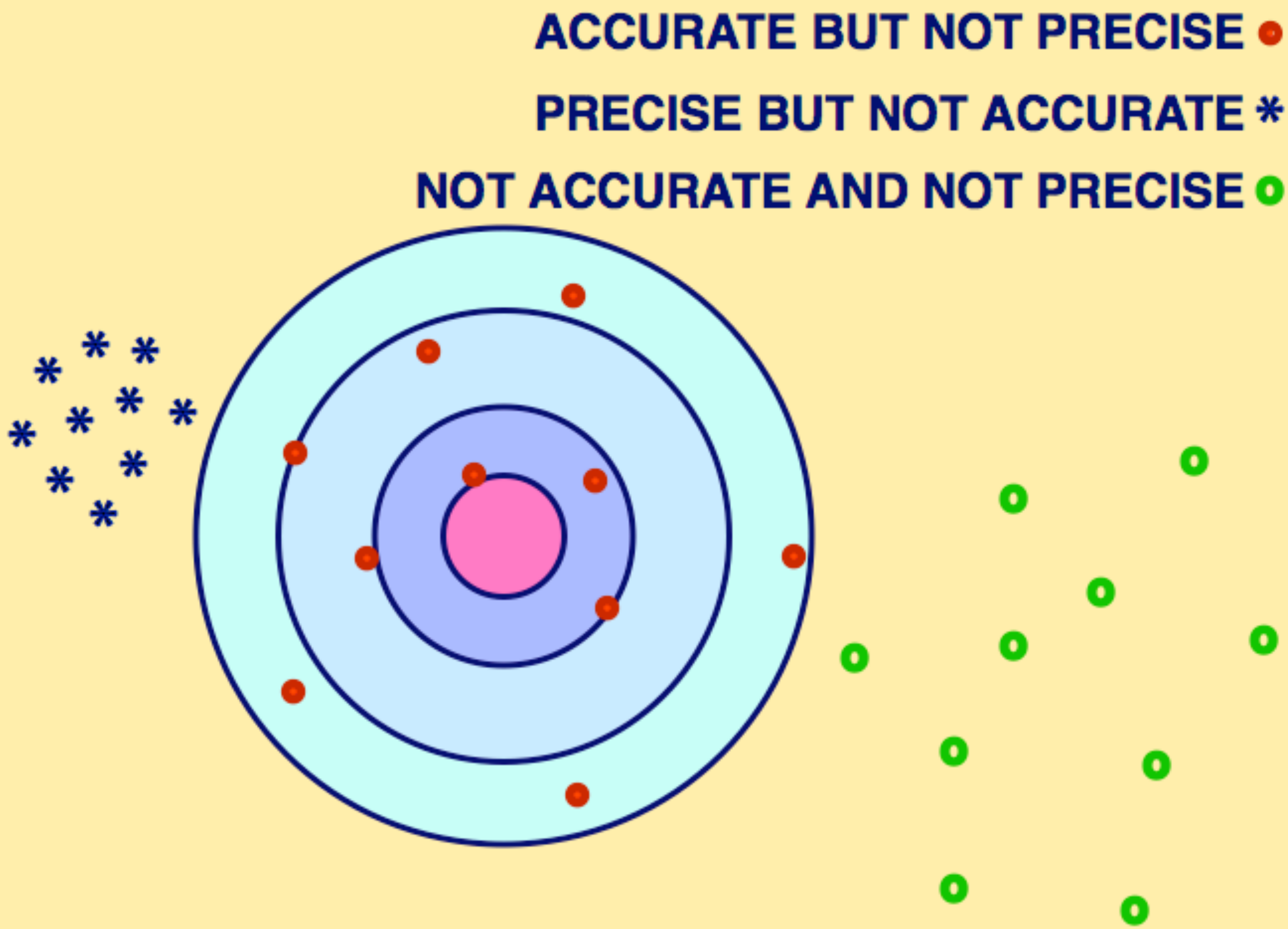
# Three-part Assessments

- 7 Alaska 1:250,000 scale quadrangles (1975-81)
- 4 1:1,000,000 sections of Alaska, US (1978)
- 3 US 1:250,000 scale quadrangles (1982-92)
- Colombia 1:1,000,000, descriptive & g-t models pub. (1983-84)
- U.S. Forest wilderness tracts Pacific Mountain System, US (1986)
- Costa Rico 1:500,000 (1987)
- Lode Sn deposits of Seward P. Alaska (1989)
- Bolivia (1991)
- Northern Spotted Owl, NW CA, W OR, and W WA, US (1991)
- Kootenai National Forest, US (1992)
- Tongass National Forest, US (1992)
- Nevada, US 1:1,000,000 (1993-96)
- Venezuela (1993)
- Puerto Rico (1993)
- US National assessment 1:1,000,000 (1996-02)
- Bendigo orogenic Au, Victoria, Australia 1:100,000 (2006-07)
- Porphyry Cu, South America 1:1,000,000 (2005-2007)




# PRECISION AND ACCURACY

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# Reducing Biases:

- Design a system to reduce chances of biases
- Provide guidelines

# Why Three-part Form of Assessment

- Three-part assessments are founded in decision analysis to provide a standard framework for making decisions concerning mineral resources under conditions of uncertainty

- The goal is to provide unbiased resource information in a form useful to decision-makers

# Mineral Deposit Models Are Used to Reduce Uncertainty About:

- General locations of resources
- Grades and tonnages of deposits
- Number of deposits
- Value of resources

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# Types of Mineral Deposit Models:

- Descriptive models
- Grade and tonnage models
- Density or Spatial models
- Cost models
- Geoenvironmental models

# Delineating Tracts

- Boundaries of a permissive tracts are drawn such that the probability of the deposit occurring outside the boundary is negligible; that is less than 1 in 100,000 to 1,000,000

- Preliminary tracts should be examined to determine if parts have been explored so thoroughly that they can be confidently said to lack deposits—if so eliminate. When drawing our tracts, we must consider spatial differences in the:
  1. Probability of occurrence, and
  2. Probable distribution of undiscovered deposits

# Delineating Tracts

- Designation of a tract as permissive does not imply any special favorability for the occurrence of a deposit, nor does it address the likelihood that a deposit will be discovered there if it exists
- Favorability for a deposit type is represented by the number of undiscovered deposits perceived to exist in a tract
- In three-part assessments, it is desirable to subdivide a permissive tract into two or more new tracts if they have different kinds of information, different numbers of undiscovered deposits, or possibly different amounts of uncertainty about the number of deposits

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# Estimating Number of Deposits

- The third part of an assessment is estimation of some fixed, but unknown number of deposits of each type that exist in the delineated tracts

- Estimates of number of deposits explicitly represent the probability (or degree of belief) that some fixed but unknown number of undiscovered deposits exist in the delineated tracts

- As such, these estimates reflect both the uncertainty of what may exist and a measure of the favorability of the existence of the deposit type

# Estimation

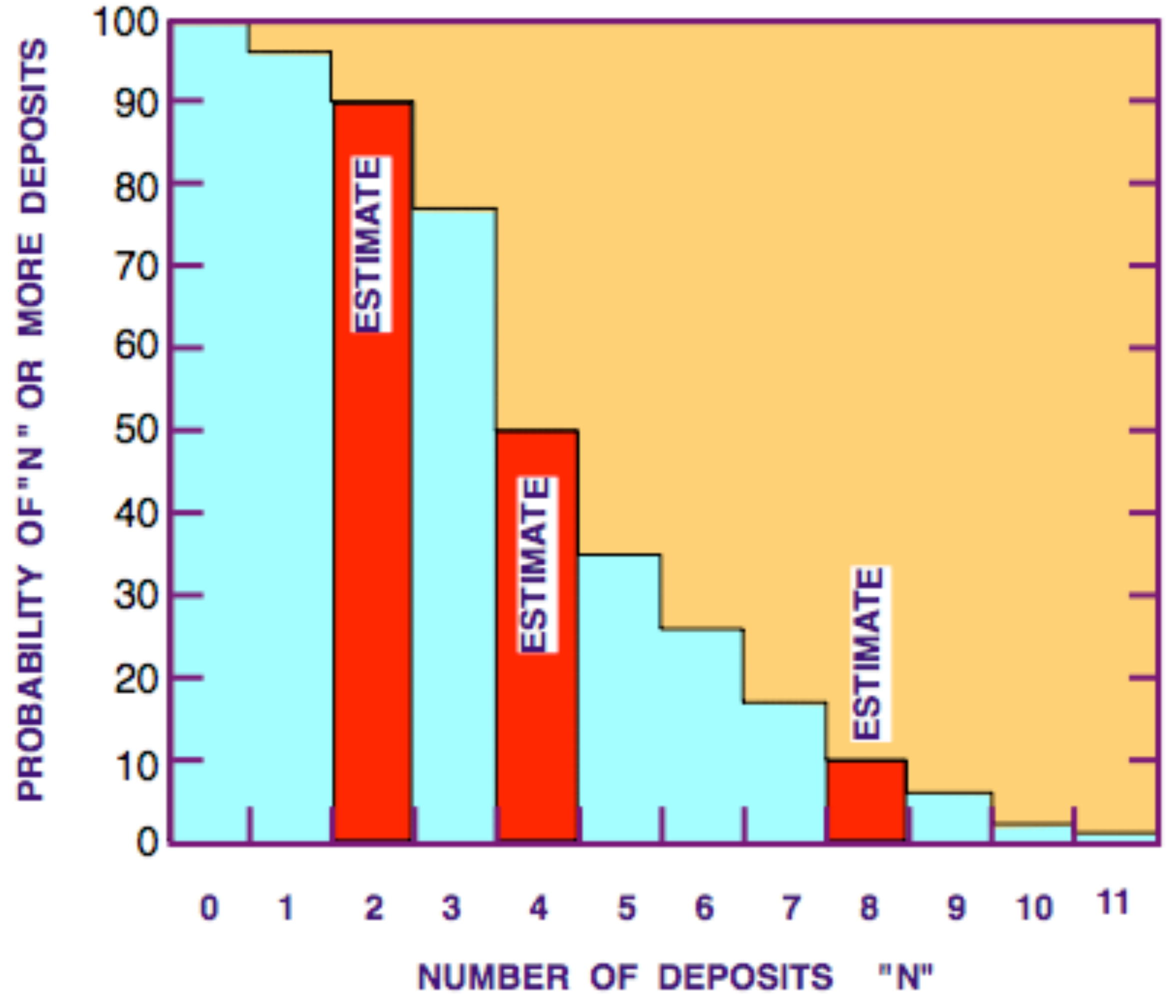
- In practice, a small group of scientists who are knowledgeable about the deposit type (and advised by regional experts) typically make consensus estimates
- Two general strategies tend to be used:

  1) Individual occurrences, prospects, and indicators are assigned probabilities and the results combined

  2) Estimator uses models of deposit densities in well-explored areas or recalls from experience many other areas that are geologically similar to the area being assessed and are well explored, and uses the proportions of deposits in these other areas to make the estimates for the new area

# Estimating Undiscovered Deposits—
## the form of the estimates

**The relation of number of deposits estimates for probabilities of 0.9, 0.5, and 0.1 to the underlying probability distribution**



Three estimates of number of undiscovered deposits with interpolated values.

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# Guidelines For Number Of Deposits Estimates

- Grade and tonnage model
- Deposit density models
- Statistical guides–coefficient of variation
- Counting and assigning probabilities to anomalies
- Process constraints
- Relative frequencies of related deposit types
- Area spatial limits
- Total known metal
- Exploration extent and efficiency

# Number of Deposit Estimation

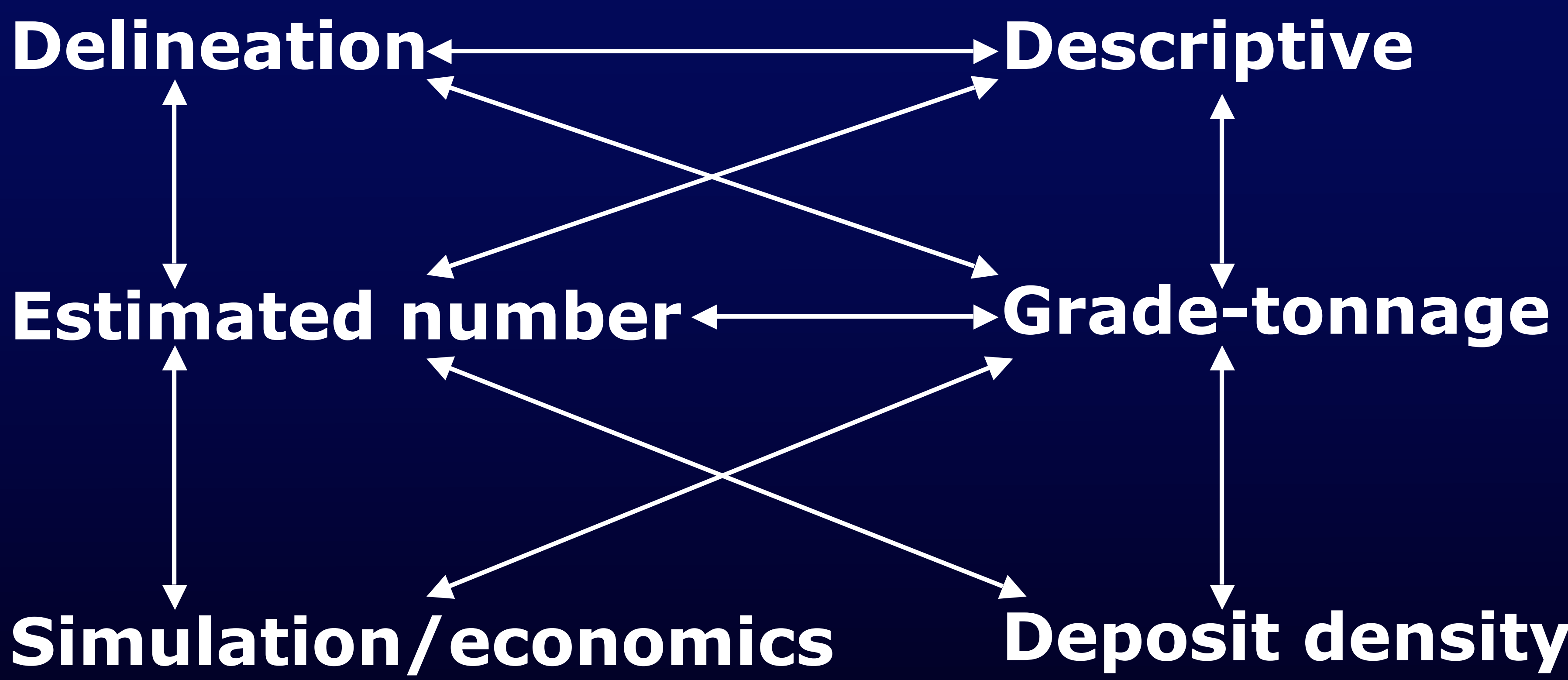
- Permissive areas frequently covered, need to make estimates not based only on prospects
- Estimates not main source of error, but source of concern by geologists
- Estimates typically made by expert judgment
- No evidence of bias in subjective estimates in meteorology, best estimates after machine guidance

# Reducing Biases:

- **Design a system to reduce chances of biases**
- **There are estimation process issues that can point to bias such as the expert not following standard statistical or logical rules (Meyer and Booker, 2001)**
- **The most straightforward way to identify bias is to use the same tools that are available as guidelines**
- **Estimates that are inconsistent with guidelines should at the least raise questions about possible bias**

(Meyer, M.A., and Booker, J.M., 2001, Eliciting and analyzing expert judgment: A practical guide: American Statistical Association and Society for Industrial and Applied Mathematics)

# Preventing Biased Quantitative Resource Assessments Requires Consistency

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# Some Applications of Mineral Resource Assessments:

- To plan and guide exploration programs,
- To assist in land use planning,
- To plan the location of infrastructure,
- To estimate mineral endowment, and
- To identify deposits that present special environmental challenges

# Three-part Assessments Are Desirable Because They:

- Respond to most customer needs
- Produce unbiased estimates
- Allow use of variety of information types
- Allow use of many methods
- Explicitly represent uncertainty
- Are designed for economic analysis

# Keys to Success of USGS 3-part Form of Assessment

- System designed with customers in mind
- 30 years of improvements through research
- An internally consistent system of models:
  - Descriptive
  - grade and tonnage
  - deposit density
  - economic filter

**Without data, you are just one more person with an opinion**

**Without a consistently applied set of rules, you just have data, not information**

**Without an assessment purpose, you are just providing a report, not unbiased information useful to decision-makers**